

# Sensitivity of ionosonde detection of atmospheric disturbances induced by seismic Rayleigh waves at different latitudes 2. Aeronomy

Maruyama T., Shinagawa H., Yusupov K., Akchurin A.  
*Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia*

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## Abstract

© 2017 The Author(s). Ionospheric disturbance was observed in ionograms at Kazan, Russia (55.85°N, 48.81°E), associated with the M8.8 Chile earthquake in 2010 (35.91°S, 72.73°W). The disturbance was caused by infrasound waves that were launched by seismic Rayleigh waves propagating over 15,000 km along Earth's surface from the epicenter. This distance was extremely large compared with the detection limit of similar ionospheric disturbances that were previously studied at lower latitudes over Japan. The observations suggest that the sensitivity of ionograms to coseismic atmospheric disturbances in the infrasound range differs at different locations on the globe. A notable difference in the geophysical condition between the Russian and Japanese ionosonde sites is the magnetic inclination (dip angle), which affects the ionosphere-atmosphere dynamical coupling and radio propagation of vertical incidence ionosonde sounding. Numerical simulations of atmospheric-ionospheric perturbation were conducted, and ionograms were synthesized from the disturbed electron density profiles for different magnetic dip angles. The results showed that ionosonde sounding at Kazan was sensitive to the atmospheric disturbances induced by seismic Rayleigh waves compared with that at Japanese sites by a factor of  $\sim 3$ . Graphical Abstract: [Figure not available: see fulltext.]

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## Keywords

Earthquakes, Infrasound, Ionosonde, Lithosphere-atmosphere-ionosphere coupling, Rayleigh waves

## References

- [1] Artru J, Farges T, Lognonné P (2004) Acoustic waves generated from seismic surface waves: propagation properties determined from Doppler sounding observations and normal-mode modelling. *Geophys J Int* 158:1067-1077
- [2] Berngardt OI, Kotovich GV, Mikhailov SY, Podlesnyi AV (2015) Dynamics of vertical ionospheric inhomogeneities over Irkutsk during 06:00-06:20 UT 11/03/2011 caused by Tohoku earthquake. *J Atmos Solar Terr Phys* 132:106-115
- [3] Calais E, Minster JB (1995) GPS detection of ionospheric perturbations following the January 17, 1994, Northridge earthquake. *Geophys Res Lett* 22(9):1045-1048
- [4] Capon J (1970) Analysis of Rayleigh-wave multipath propagation at LASA. *Bull Seism Soc Am* 60(5):1701-1731

- [5] Chum J, Hruska F, Zednik J, Lastovicka J (2012) Ionospheric disturbances (infrasound waves) over the Czech Republic excited by the 2011 Tohoku earthquake. *J Geophys Res* 117:A08319. doi: 10.1029/2012JA017767
- [6] Chum J, Liu JY, Laštovička J, Fišer J, Mošna Z, Baše J, Sun YY (2016) Ionospheric signatures of the April 25, 2015 Nepal earthquake and the relative role of compression and advection for Doppler sounding of infrasound in the ionosphere. *Earth Planets Space* 68:24. doi: 10.1186/s40623-016-0401-9
- [7] Davies K (1969) *Ionospheric radio waves*. Blaisdell Publishing Company, Waltham
- [8] Hedin AE (1991) Extension of the MSIS Thermosphere Model into the middle and lower atmosphere. *J Geophys Res* 96(A2):1159-1172. doi: 10.1029/90JA02125
- [9] Lay T, Wallace TC (1995) *Modern global seismology*. Academic Press, San Diego
- [10] Leonard RS, Barnes RA (1965) Observation of ionospheric disturbances following the Alaska earthquake. *J Geophys Res* 70(5):1250-1253
- [11] Liu JY, Sun YY (2011) Seismo-traveling ionospheric disturbances of ionograms observed during the 2011  $M_w 9.0$  Tohoku Earthquake. *Earth Planets Space* 63:897-902
- [12] Liu JY, Chen CH, Sun YY, Chen CH, Tsai HF, Yen HY, Chum J, Lastovicka J, Yang QS, Chen WS, Wen S (2016) The vertical propagation of disturbances triggered by seismic waves of the 11 March 2011  $M_w 9.0$  Tohoku earthquake over Taiwan. *Geophys Res Lett* 43. doi: 10.1002/2015GL067487
- [13] Maruyama T, Shinagawa H (2014) Infrasonic sounds excited by seismic waves of the 2011 Tohoku-oki earthquake as visualized in ionograms. *J Geophys Res* 119:4094-4108. doi: 10.1002/2013JA019707
- [14] Maruyama T, Tsugawa T, Kato H, Saito A, Otsuka Y, Nishioka M (2011) Ionospheric multiple stratifications and irregularities induced by the 2011 off the Pacific coast of Tohoku Earthquake. *Earth Planets Space* 63:869-873
- [15] Maruyama T, Tsugawa T, Kato H, Ishii M, Nishioka M (2012) Rayleigh wave signature in ionograms induced by strong earthquakes. *J Geophys Res* 117:A08306. doi: 10.1029/2012JA017952
- [16] Maruyama T, Yusupov K, Akchurin A (2016a) Ionosonde tracking of infrasound wavefronts in the thermosphere launched by seismic waves after the 2010  $M 8.8$  Chile earthquake. *J Geophys Res Space Phys* 121:2683-2692. doi: 10.1002/2015JA022260
- [17] Maruyama T, Yusupov K, Akchurin A (2016b) Interpretation of deformed ionograms induced by vertical ground motion of seismic Rayleigh waves and infrasound in the thermosphere. *Ann Geophys* 34:271-278. doi: 10.5194/angeo-34-271-2016
- [18] Nishitani N, Ogawa T, Otsuka Y, Hosokawa K, Hori T (2011) Propagation of large amplitude ionospheric disturbances with velocity dispersion observed by the SuperDARN Hokkaido radar after the 2011 off the Pacific coast of Tohoku Earthquake. *Earth Planets Space* 63:891-896
- [19] Ogawa T, Nishitani N, Tsugawa T, Shiokawa K (2012) Giant ionospheric disturbances observed with the SuperDARN Hokkaido HF radar and GPS network after the 2011 Tohoku earthquake. *Earth Planets Space* 64:1295-1307
- [20] Rees MH (1989) *Physics and chemistry of the upper atmosphere*. Cambridge University Press, Cambridge
- [21] Rolland LM, Lognonné P, Astafyeva E, Kherani EA, Kobayashi N, Mann M, Munekane H (2011) The resonant response of the ionosphere imaged after the 2011 off the Pacific coast of Tohoku Earthquake. *Earth Planets Space* 63:853-857
- [22] Tanaka T, Ichinose T, Okuzawa T, Shibata T, Sato Y, Nagasawa C, Ogawa T (1984) HF-Doppler observations of acoustic waves excited by the Urakawa-Oki earthquake on 21 March 1982. *J Atmos Terr Phys* 46(3):233-245
- [23] Tsugawa T, Saito A, Otsuka Y, Nishioka M, Maruyama T, Kato H, Nagatsuma T, Murata KT (2011) Ionospheric disturbances detected by GPS total electron content observation after the 2011 off the Pacific coast of Tohoku Earthquake. *Earth Planets Space* 63:875-879
- [24] Wolcott JH, Simons DJ, Lee DD, Nelson RA (1984) Observations of an ionospheric perturbation arising from the Coalinga earthquake of May 2, 1983. *J Geophys Res* 89(A8):6835-6839
- [25] Yuen PC, Weaver PF, Suzuki RK, Furumoto AS (1969) Continuous, traveling coupling between seismic waves and the ionosphere evident in May 1968 Japan earthquake data. *J Geophys Res* 74(9):2256-2264
- [26] Yusupov K, Akchurin A (2015) Incredibly distant ionospheric responses to earthquake. *Geophys Res Abs* 17:EGU2015-15198-1